INFLUENCE OF CHEMICAL AND TEXTURAL CHARACTERISTICS ON GEOMECHANICAL PROPERTIES OF SANDSTONE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY & MASTER OF TECHNOLOGY

(DUAL DEGREE)

IN
MINING ENGINEERING

BY
DEBADURLABHA DASH
710MN1099

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008
2015

INFLUENCE OF CHEMICAL AND TEXTURAL CHARACTERISTICS ON GEOMECHANICAL PROPERTIES OF SANDSTONE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY & MASTER OF TECHNOLOGY

(DUAL DEGREE)

IN
MINING ENGINEERING

BY
DEBADURLABHA DASH
710MN1099

Under the guidance of
Dr. SK. MD. EQUEENUDDIN
Assistant Professor

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008
2015

NATIONAL INSTITUTE OF TECHNOLOY

CERTIFICATE

This is to certify that, the thesis entitled "**INFLUENCE OF CHEMICAL AND TEXTURAL CHARACTERISTICS ON GEOMECHANICAL PROPERTIES OF SANDSTONE**" submitted by Sri Debadurlabha Dash (Roll No 710MN1099) in partial fulfillment of the requirements for the award of Bachelor of Technology & Master of Technology (Dual degree) in Mining Engineering at National Institute of Technology is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the report has not been submitted to any University/Institute for the award of any Degree or Diploma.

Date

Dr. Sk. Md. Equeenuddin
Assistant Professor
Department of Mining Engineering
NIT, Rourkela-769008

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

ACKNOWLEDGEMENT

I would like to express my deep appreciation to my project guide **Prof. Sk. Md. Equeenuddin,** who has always been a source of motivation to me for carrying out the project. His constant inspiration and invaluable guidance and suggestions have helped me in shaping this project very well. I am thankful to him for giving me his valuable time despite of his busy schedule to help me complete my project.

I am immensely thankful to **Prof. H. K. Naik,** Head of the Department (Mining Engineering) for allowing me to use the facilities available in the department beyond office hours. I would also like to thank **Prof. M.K .Mishra** for allowing me to work in rock mechanics and geomechanics laboratory .A word of thanks goes to **Mr. Premananda Mallick** and **Mr. Bhaskar Chandra Jena** for helping to carry out the experiments.

I also express my thanks to the staff members of department of Earth and Atmospheric Sciences for providing me necessary facilities to carry out texture analysis.

Debadurlabha Dash
Department of Mining Engineering
National Institute of Technology
Rourkela – 769008

ABSTRACT

To find out the influence of chemical and petrographic characteristics on geomechanical properties of sandstone, samples are collected from mines of Mungoli Opencast Mine (Western Coalfields Limited), Lakahnpur opencast mine (Mahanadi Coalfileds Limited) and Tamnar opencast mine (Jindal Power Limited). The samples from WCL are both coarse and fine grained but the samples from MCL are coarse grained. .However medium grained sandstone, shaly sandstone and ferruginous sandstones were collected from JPL. Specimens were prepared from the samples and tested for uniaxial compressive strength (U.C.S.), point load strength (P.L.S), Brazilian tensile strength (B.T.S), dry and saturated densities, porosity. Strength has found to be increased with decrease in porosity. Mineralogy and chemical composition were found out by XRD and XRF tests respectively. Quartz and kaolinite are the dominant minerals in this study. Siderite is dominant in fine grained sandstone of JPL.Strength has found to be increased with percentage of Ca, Mg and Fe concentration. Thin sections were prepared to study the texture of the sandstone, which were then analyzed by polarized optical microscope. Petrographic properties such as packing density and packing proximity were determined which were found to affecting the strength of the strength of the sandstone. They were found to be varied from 28.2% to 86.75% and 17.23% to 74.17% respectively. A strong relationship is observed for packing proximity with the strength of the sandstone. It was found that the U.C.S of the sandstone found to be varied from 13.82 MPa to 47.4 MPa. Similarly the point load strength and Brazilian tensile strength was found to be varied from 0.36 MPa to 5.38 MPa and 0.22 MPa to 7.2 MPa respectively. Besides these the dry density, saturated density and porosity have been found to be varied from 1.85 g/cc to 2.47 g/cc and 2.02 to 2.61 g/cc respectively.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Sandstone is typically associated as the overburden of the coal seams. So while extracting coal seams removal of sandstone is necessary in opencast workings where as in underground mines work is done below the sandstone roof. As the sandstones are sedimentary in nature, the rock cores are of poor quality, so mechanical tests are not possible in most of the cases. Hence, the mechanical properties can be estimated from index tests which needed to be correlated with mechanical properties. Petrographic properties, which are studied through microscopic inspections, such as texture and mineralogy can be correlated to the rock strength (Fahy and Guccione, 1979).

Sandstones have a variety of rock types with different mineralogy, petrographic characteristics and geomechanical properties. The variations in geomechanical and physical properties have been found due to the variation of petrographic characteristics (Bell, 1978; Howarth and Rolands, 1986; Shakoor and Bonelli, 1991). Petrographic properties of sandstone such as grain size, packing density, packing proximity, degree of grain interlocking, void space and mineral interlocking affect mechanical properties (Shakoor and Bonelli, 1991).

Statistical techniques can be utilized for the prediction of strength properties of sandstone from petrographic study when the samples are unsuitable for testing of strength (Bell, 1978; Richards and Bell, 1995; Fahy and Guccione, 1979; Shakoor and Bonelli, 1991; Bell and Culshaw, 1998; Prikryl, 2001). Linear regression appeared to be suitable for prediction of strength for a particular location. Rock strength is treated as most important parameter in rock mechanics (Price, 1960; Prikryl, 2001). Different rock strength is explained by various factors such as grain size, shape, degree of interlocking, preferred orientation, mineral composition, quartz content, matrix content (mostly consists of silt and clay), density, moisture content, porosity and state of alteration.

(Hawkes and Mellor, 1970; Spry, 1976; Howarth and Rowlands, 1986 Dobereiner and De Freitas, 1986; Hawkins and McConnell,1990; Shakoor and Bonelli, 1991; Edet,1992; Bell and Culshaw, 1993; Howarth and Rowlands, 1986; Rashed and Sediek, 1994; Kasim and Shakoor, 1996; Bell and Lindsay,1999; Tugrul and Zarif, 1999). Petrographic properties of rocks are the intrinsic properties on which the mechanical properties of rocks are dependent (Singh et al., 2001). According to Merian et. al (1970) texture is the properties of grains includes relative amounts, size and shape of the grains and their interlocking. As the petrographic properties are controlling strength parameters, the petrographic properties are determined to find out its effect on the strength of the sandstone.

1.2 OBJECTIVES

- Determination of geomechanical properties of rock such as U.C.S, B.T.S, P.L.S, Dry density, Saturated density, Porosity
- Study of the chemical and mineralogical properties
- Fabric of rock

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Headari et al. (2013) studied the mechanical, petrographical properties and mineral compositions from the Jurassic sandstone, Iran and have found variations in mechanical properties with respect to petrographic properties. The mechanical properties which were tested are U.C.S, point load strength index, porosity, dry and saturated densities. The petrographic properties which they were studied were the relative percentage of grain contacts, packing density, packing proximity were determined by Kahn (1956) method. Quartz, Feldspar, rock fragments, mica, calcite and matrix content were determined. Multivariable regression analysis was applied to find out relationship between them and concluded petrographic properties have more impact than chemical composition. They concluded that packing density, packing proximity and percentage of long contacts have more influence on the strength properties of the sandstone. The densities were found to be varied most with respect to the packing density and packing proximity. The chemical composition was found to affect less to the strength properties.

Singh et al. (2001) predicted of strength properties from mineralogy and petrographic properties of some Indian schist by using neural network with learning algorithm which operates in back propagation method. XRD was carried out for finding out major mineral constituents. Mineralogy of schist is basically quartz, mica, feldspar and chlorite. The petrographic properties of rocks were taken as input variables. Strength properties are more influenced by aspect ratio, form factor, area weighting and orientation of foliation plane. Strength properties such as U.C.S, Point load strength and Brazilian tensile strength were successfully predicted from mineralogical composition which includes quartz, feldspar, mica, chloride, clay and petrographic properties such as area weighting, form factor and aspect ratio.

Samsuri et al. (1999) found out relationship between petrographic rock properties with strength parameters of sandstones from the Pahang, Malaysia. The evaluations of mechanical properties such as compressive, tensile strength, young modulus, shear strength in relation to the petrographical properties such as grain size, sorting, cementation. Sandstones are dominated with quartz content (49.9% to 60.1%) followed by feldspar (7 % to 16.8 %), mica (0.5 % to 7.3 %) and some rock fragments such as quartzite, schist and chert. The cementing materials are basically composed of clays, carbonates and quartz. They concluded that presence of quartz and other stable materials such as plagioclase and feldspar increases the strength. The presence of mica and other grains decrease the strength of rocks. Besides these samples with poorly sorted sand have higher strength values as the amount of grain contacts per volume increases with the poorly sorted sandstones. In short sandstones which are poorly sorted, finer grain size and having higher quartz content and lower amount of mica have higher strength properties and more stable.

Bell and Lindsay (1999) studied the influence of the petrographic properties of sandstone on mechanical properties of sandstone from Newspaper member of the Natal group near Durban, South Africa. The sandstones are rich in quartz content and in some cases orthoclase is principally found. The petrographic properties such as grain size distribution, packing density, types of grain contact, length of grain contact, amount of void space, type and amount of cement matrix material were found to be affecting the geomechanical properties. The mechanical properties included were U.C.S, tensile strength and point load and Schmidth hardness. The strength was found to be increased with increase in hardness number. Strength properties were found to be increased with increasing packing density, contact area and total contact type where as it decreases with increase in porosity. They have also found increase in harness with increase in density. They observed that decrease in clay content and increase in quartz content have led to increase in strength of sandstone.

Jeng et al. (2004) studied about the variation of geotechnical properties of sandstones from Taiwan. The laboratory study of geotechnical properties includes dry density, porosity of Tertiary sandstone. There was reduction of strength in some sandstone which was better represented by a parameter called strength reduction ratio (R). He observed that variations in geotechnical properties such as strength, dry density, and porosity are due to the petrographic properties such as grain area ratio (GAR), packing density, form factor and mineralogy of grains. Mineral composition was found out by semi quantitative XRD tests. The mineralogy of grains include quartz (%), feldspar (%) and rock fragments (%). The U.C.S was predicted based on the grain area ratio and porosity. The samples have more strength if they are having more grain area ratio and have lesser porosity.

Tarmakar et al. (2007) found out relationships between mechanical physical properties, composition and texture of sandstone from Siwalik Group at the foot hills of Himalay, Nepal. The sandstones were having ferruginous, calcitic and siliceous cements in between the boundaries. Mechanical properties such as U.C.S, point load strength ,dry density, saturated density, porosity were determined .Twenty two Petrographic properties such as total strong cement over matrix, strong cement over total cement ,packing density, packing proximity were determined. They are used for correlating mechanical properties between the most influencing petrographic properties were determined by t-test. Among them void and sphericity explains hardness mostly. Point load strength index found to be varied mostly with void space and strong over weak cement (SOWC) and grain to void contact. U.C.S have strong relationship with low void space, strongly cemented and grain facing voids. Multiple regression and correlation analysis was used for finding out relationship between the petrographic properties and mechanical properties.

Hsieh et al. (2008) collected sandstone samples of Kweichulin formations of Taiwan and studied how macroscopic mechanical properties of sandstone such as uniaxial compressive strength and Young's modulus were going to be affected by their petrographic properties such as porosity and grain area ratio. They used numerical analysis based on bonded particle model. They considered three types of particles such as grain particle (GP), matrix particle (MP), porous particle (PP) and corresponding six different bonds between them. The particles are contacted by different bonds between them the bonds where porous matrix material was involved found to be weakest. Variation of U.C.S with Grain area ration and porosity was observed.

Zorlu et al.(2008) collected sandstone samples from Ankara, Turkey and found out the relationship between petrographic properties and strength in order to discuss the key petrographic properties governing the U.C.S to develop a model for prediction of strength of sandstone. The study was mainly based on the determination of mineralogical composition of sandstone which were determined by grain and binding material type. The mean grain size was determined by measuring maximum diameters of 100 grains in each thin section. The shape of the grain was studied based on the roundness and which have shown that majority of grains have shape of sub angular to angular and low degree of sphericity. Straight contacts were mostly found as grain contacts which were followed by concavo-convex grain contacts as a result the sandstones were found to be weak in nature. Packing density was found to be low. Packing proximity is having values in medium ranges. The sandstones were weak due to randomly oriented joints .The strength was found to varied most with respect to packing density, saturation, quartz cement and matrix content. The matrix was negatively co related with strength of sandstone.

Stuck et al. (2013) analyzed petrographical data from 22 selected sandstone of Germany to identify the similarity between sandstones and grouping them. Petrographic analysis was carried out by point counting method.XRD and XRF analysis were carried out for finding out the chemical composition of sandstone. Mercury porosimetry was used for the determination of pore radii. Strength parameters such as U.C.S, Tensile strength, point load strength were determined which were found to be varied depending on the porosity and type of grain contacts. Petrographic study revealed that the grains which are having pointed and elongated grain contacts have lesser strength properties whereas sandstones which are having sutured and concavo-convex contacts have higher strength .Strength was also found to be decreased with unstable lithic fragments.

Chen and Hu (2003) collected sandstone samples from Shihti and Kweichulin Formations of Taiwan and studied how the uniaxial compressive strength varies as compared to mineralogical properties such as quartz, matrix content. They found that U.C.S was inversely co related with quatz content. They have also found that U.C.S decreased with increased in water content. They also reported that strength was inversely correlated with the porosity. They have also found that strength was decreased as the particle size increases. All these sandstones were weak because they had poorly cemented.

Cantisani et al. (2013) studied mineralogical, petrographical, physical and mechanical properties of sandstones from Florence, Italy in order to evaluate their durability. It was observed that sandstones having higher strength were basically finer in grain size and better sorting along with there is presence of significant amount of carbonate cement. It was also found that samples which were having clay as matrix content they had lesser strength as clay content increases porosity.

Sabatakakis et al. (2008) collected sandstone and limestone samples from Greece and studied petrographic properties of sedimentary rocks by thin section analysis using a standard polarizing microscope. The analysis of petrographical properties include the main rock forming minerals, grain size, grading of grains, contact type between grains in thin section analysis. They found the quartz, feldspar and calcium carbonate as crystal fragments. Clay was the dominant matrix material. The strength has increased with increase in percentage of quartz and basically due to the presence of granular materials. Increase in strength in granular materials is due to its ability to accumulate large amount of external stress. Angular poor sorted grains have also increased the strength. They concluded that petrographic properties have strong influence in strength of rocks.

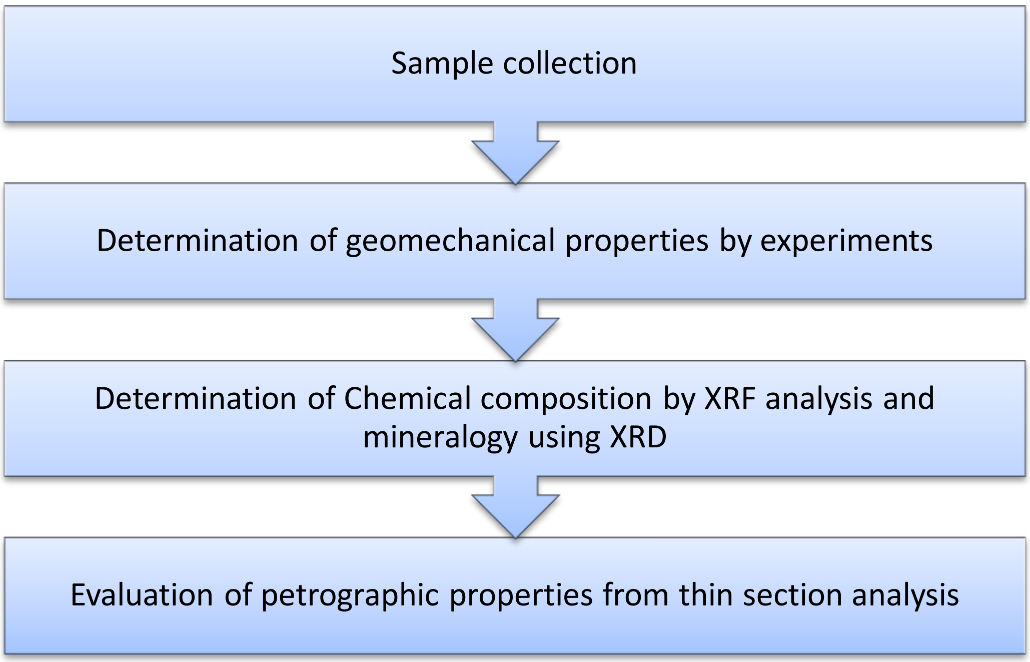
Přikryl (2001) reported the variation of the strength properties with the microstructural properties. Microstructures were analyzed using thin section using SIGMASCAN software. The study of thin section analysis used the process of image acquisition, pre-processing, digitizing, measurement and analysis of data. The petrography study involves determination of size, shape and orientation of grains. It was noticed that higher strength have occurred due to fine grained particles and the increase in grain size had resulted in decrease in strength of rock. Higher anisotropy had also led to the increase in strength. The strength had also found to be decreased with increase in square root of grain size. Hardness was also found to be increased with the amount of fine grained particles.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

The brief procedure of the project is given below.



3.2 SAMPLE COLLECTION

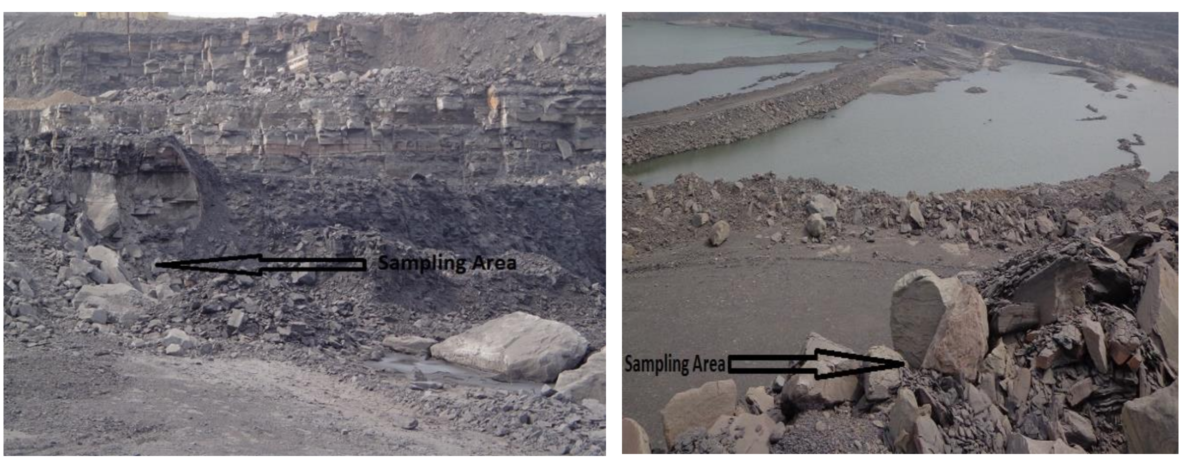
3.2.1 Lakhanpur Opencast project

Lakahnpur opencast project (LOP) belongs to Ib valley of Mahanadi Coalfield limited (MCL). Here mining is carried out with the help of Surface miner. The mine is situated in Lakhnpur tahasil of Jharsuguda district. The mine lies between latitudes $21^{0}43^{I}30^{II}$ to $21^{0}46^{I}44^{II}$ and longitudes $83^{0}49^{I}11^{II}$ to $83^{0}52^{I}38^{II}$. In Lakhanpur mine there are five coal seams namely Belpahar, Parkhanni, Lajkura, Rampur and IB seams. Currently working is done in Lajkura seam. The samples are collected from overburden bench 4 of quarry 1 of Lajkura seam. The sandstones are medium grained sandstone.

Figure 3.1: Overburden Bench 4 of quarry 1, Lakahnpur mines ,MCL

3.2.2 Tamnar opencast project

The sandstone samples are collected from different overburdens of Jindal opencast mine situated at Tamnar, near raigarh of Chhatishgarh. It is a captive mine of Jindal thermal power plant. Mining is carried out by typical drilling and blasting operation. The mine is situated in between longitudes of $83^{0}29^{I}40^{II}$ to $83^{0}32^{I}32^{II}$ and latitude $22^{0}09^{I}15^{II}$ to $22^{0}05^{I}44^{II}$ which falls in toposheet no 64 N/12. The samples are collected from IX, VIII, VII seam overburden. The sandstones of VII O/B are typically slightly reddish in colour. The sandstones of VII seam O/B are of iron dominant sandstones. However IX O/B sandstones are of shaly sandstones. The VIII sandstones are of medium grained sandstone.



(Overbudern of VII O/B) (Overburden of IX O/B)

Figure 3.2: Overburden benches of Jindal Opencast mines Tamnar, Raigarh

3.2.3 Mungoli opencast project

It is a part of the south western portion of the western limb of the Wardha valley coal field limited, which is basically a part of the WCL. Mining activity is carried out by conventional shovel dumper combination.

The general strike of the seam varies from N 14^0 E to S 14^0 Wand the dip of the coal seam is 7 ^{0}to 9^0 in direction S 76^0 W. Sandstones are collected from three different layers and from different locations. The layers are of formations of Kamthi, Motur, Barakar from top to bottom. The coarse grain sandstone was fond in upper layer i.e kamithi formation. Motur formation has medium grained sandstone and Barakar formation has fine grained sandstone.

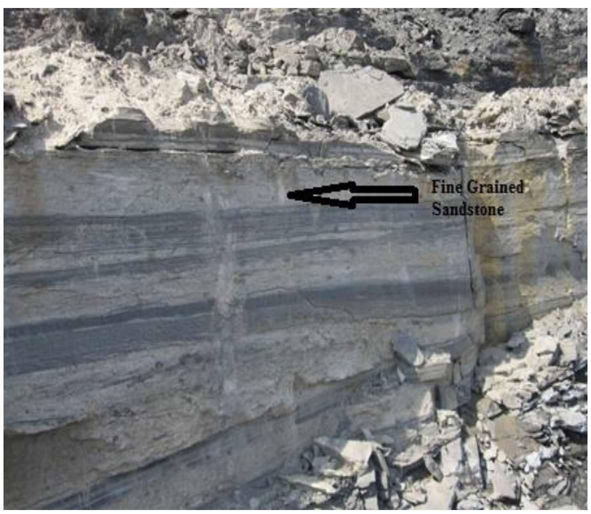


Figure 3.3: Mungoli Opencast Project, WCL

3.3 EXPERIMENTAL WORK

3.3.1 Sample Preparation

Block samples which are collected are cored to 54 mm (NX size) diameter by universal coring machine. Where the NX size core preparation is not possible 48 mm core samples were prepared. Basically for the samples from WCL 48 mm diameter cores are prepared .After the preparation of core they are cut of suitable sizes for different tests .For Uniaxial testing Samples of L/D ratio of 2.5 to 3 are prepared. For Brazilian test and point load test the sample of L/D ratio 0.5 and 1.5 to 2 respectively.

3.3.2 Unconfined Compressive Strength (U.C.S)

According to the ASTM-D2166, the unconfined compressive strength is defined as the compressive stress at which the cylindrical sample which is not confined fails. It is an representation of strength parameters of rocks.

Test specimen

It is a right circular cylinder mad in accordance with IS-9179-1979 and it is tested at moisture content similar to the field.

Dimension

- Length to diameter ratio (l/d) of the cylindrical material is maintained in between 2 to 3.
- The diameter of specimen should be greater than 45mm or it should be greater than ten times the largest diameter of the grain size.
- It should be flattened within 0.05 mm.

- The ends should be perpendicular to the axis of the specimen a little deviation is allowed up to 0.001 radian.
- The cylindrical specimen should be smooth and free from abrupt irregularities and straight to within 0.3 mm over full length of the specimen.
- The diameter of the specimen should be measured to the nearest 0.1 mm by averaging two diameters which has measured at right angles to each other.

Figure 3.4: Triaxial testing machine

Test procedure

- The surfaces of the specimen were wiped clean and after that the sample is settled down on the lower disc.
- The axis of the specimen shall be carefully aligned with the center of the thrust of the spherical seat and the movable portion of the spherically seated disc shall be adjusted.
- Load on the specimen shall be applied continuously at a constant stress rate of 0.5 MPa to 1 MPa/s, so that failure took place within 5 to 15 minutes.
- Maximum load on the specimen shall be recorded with 1 percent accuracy in Netwon,

- The number of specimen that to be tested should be determined from practical consideration. If

If P represents the load at failure and D is the sample diameter, then unconfined compressive strength id given by the formula below.

$$\boldsymbol{Unconfined\ compressive\ strength}\ (\boldsymbol{U.C.S}) = \frac{\mathbf{4.}\boldsymbol{P}}{\boldsymbol{\pi}\mathbf{D2}}$$

3.3.3 Point Load Strength (P.T.S)

It has been carried out in accordance with ASTM D5731.It enables economical testing of core or lump rock samples (Marinos and Hoek, 2001). It has been widely accepted and used as an index test for predicting the strength of the rock samples. Basically in this study diametrical load is applied.

Test Specimen

Both irregular and core samples can be tested by point load tester. While testing it should be kept in mind the moisture content is same as the field.

Dimension

- For core samples the sample length is generally two times that of the diameter.
- The diameter of the specimen is maintained near to 50 mm i.e 48mm core or NX core have been accepted without correction.
- For diametrical test it should not be flattened at both the ends rather it is seen that the diameter is maintained all over the length.

Figure 3.5 : Point load testing machine

Test procedure

- At first the sample is placed over the low indenter and the pressure is applied by hand lever up to when the sample touches the upper indenter .The separation of the platen is noted down.
- The load is applied up to which the specimen fails and the load at which it fails is noted down. Besides these final separation of the platen is noted down.
- Equivalent diameter for the test is found by subtracting the amount of closeness of platen from the actual diameter of the specimen.

If P is the load at failure and D_e is the equivalent diameter of the specimen at failure then the point load strength is given by the formula below.

$$\boldsymbol{Point\ load\ strength}\ (\mathbf{Is})\mathbf{50} = \frac{\mathbf{P}}{(\mathbf{De})\mathbf{2}}$$

3.3.4 Brazilian tensile strength (B.T.S)

The tensile stress under which a rock fails is defined as the tensile strength of the rock. In this test indirect tension is applied as compressive stress along vertical direction is accoMPanied by a tensile stress along horizontal direction. This test has been carried out in accordance with ASTM D 3967-08.

Specimen Preparation

According to international society of rock mechanics (I.S.R.M) the specimen for Brazilian test is a cylindrical disc shaped rock with thickness is half of the diameter. i.e L/D ratio is 0.5 maintained. In laboratory the specimen from cored sample was cut and polished to desired dimension.

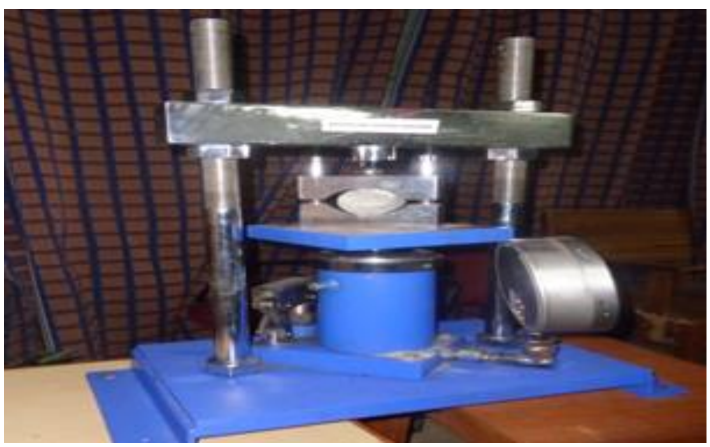


Figure 3.6: Brazilian Testing Machine

Test Procedure

- The machine is set on the suitable measuring scale and proper rate of loading with arrows set to zero.

- The specimen is set between the upper and lower platens and they are brought near specimen.
- The load is applied by the movement of the lever till the specimen fails.
- The load at which the specimen fractures was recorded.

If P is the load at failure, D is the diameter of the sample and L is the length of the sample then the tensile strength is given by the formula

$$\boldsymbol{Tensile\ strength\ (T) = \frac{2P}{\pi DL}}$$

3.3.5 Porosity

Porosity can be measured by volumetric measurements. Porosity can also be measured by geophysical logs or Petrographic image analysis. Porosity is determined in accordance to IS 18030: 1991. The basic concept is that the total volume is the sum of the porous volume and the grain volume. The porous volume can be evaluated by subtracting the grain volume from the bulk volume.

Specimen selection

At least two specimens were selected from a representative sample of material. The minimum size of each specimen should either be such that its mass is at least 50 g (for an average density rock a cube with sides of 27 mm will have sufficient mass) or such that its minimum dimension is at least ten times the maximum grain size, whichever is the greater.

Procedure

- At first the dimension of the specimen is determined which then followed by calculation of the bulk volume of the specimen. The measurement has been maintained to accurate to 0.1 mm.
- The specimen should be then placed in an oven and dried at $105^0 \pm 3^0$ C. For this test method specimens should be of sufficient coherence not to require containers, but these should be used if the rock is at all friable or fissible.
- Then the specimen is allowed to be immersed in a container where it is allowed to remain in that position for 48 hours.
- After that specimen is removed and surface dry is done by a moist cloth and the saturated mass of the specimen is measured. The saturated density is measured by dividing the bulk volume by the saturated mass.
- Proper attention should be given to remove only surface water and to ensure that no fragments are lost. The saturation mass (M sat) of the specimen is recorded.

Calculation

- The pore volume of the specimen is calculated by the following formula.

$$V_V = \frac{Msat - Mdry}{\rho w}$$

- For each specimen the bulk volume has been calculated. The porosity of the specimen is calculated by dividing total volume by the porous volume to get the porosity the below formula. It is expressed in percentage.

$$\eta = \frac{Vv}{Vt} \times 100 \text{ (in percentage)}$$

3.4 MINERALOGICAL STUDY

The sandstones samples which were collected were then crushed to -200 mesh size. The powdered sample was put into the mould of Multipurpose X-Ray Diffraction System (Rigaku Japan/Ultima-IV). Basically this machine used a copper target of wavelength 1.54 Å. The sandstone samples are analyzed for 2 theta values 5^0 to 70^0. The scanning rate was maintained 2^0/min. Corresponding intensity was recorded for the theta values which was then plotted in a graph with the help of origin software.

Figure 3.7: XRD analyzer

3.5 TEXTURAL STUDY

Texture is defined as the relationship between the materials that the rock is composed of. Several textural parameters are studied as it affects the mechanical properties of the sandstone. They are the type of grains, the matrix material; the parameters explain the contacts between them.

3.5.1 Shape, Size and sorting of grains

The size of the grains plays an important role in deciding the strength of the rock. If the particles are smaller sized then there will be increase in no of contacts. If the particle size increases then there will be propagation of crack even at lower stress. If the grains are poorly sorted then it increases the ability of the rock to accumulate larger amount of stresses.

Shape of grains is another important petrographic property which decides the strength properties. The shapes of the grains are generally expressed in terms of roundness and sphericity. Uniaxial compressive strength has a moderately strong relationship with angular grains (Shakoor and Bonelli, 1991).

There is no meaningful relationship between the uniaxial compressive strength and the sphericity but Strong relationship was observed for percentage of rounded and spherical grains (Ulusay et al., 1994).

3.5.2 Type of contacts

Sandstones with low compressive strength and high porosity basically exhibit elongated and pointed grain contacts (Stuck et al,2012). If the length of contact is more then the ability of the sandstone to take stresses increases. The higher resistance to the stresses is observed by sutured contacts as both the grains are almost interlocked. The amount of stress can be withstanded by the rock decreases from sutured contacts towards the floating contacts.

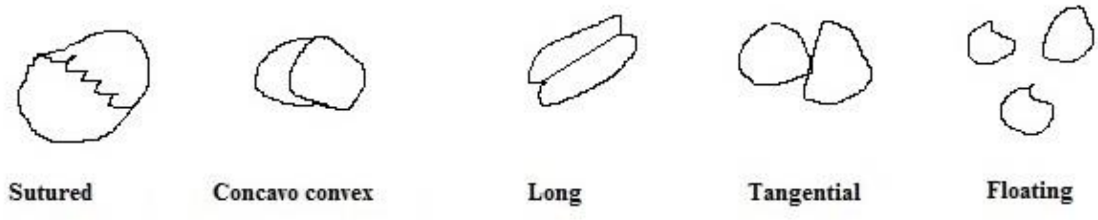


Figure 3.8 Type of contacts found in sandstone samples

3.5.3 Packing density and packing proximity

Packing density and packing proximity are two important petrographic parameters which affects the strength properties. They are quantified according to Kahn's(1956) method. Packing density (PD) is defined as the ratio of the sum of the grain length encountered along the traverse across the thin section to the total length of traverse (Kahn,1956).

$$\text{Packing density, } Pd = \frac{\sum gi}{t} \times 100(\%)$$

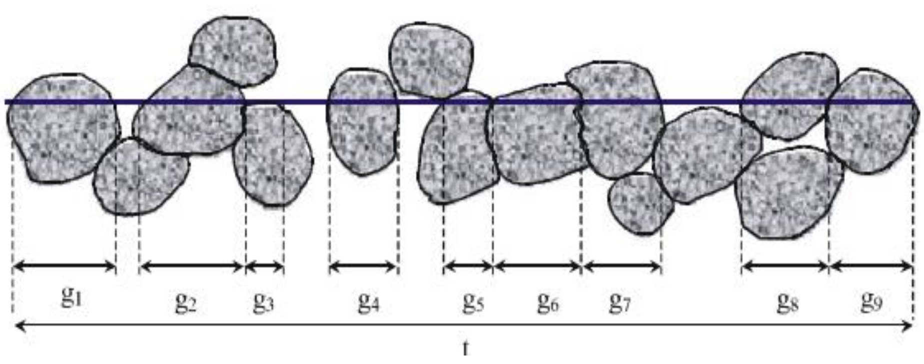


Figure 3.9: Packing density (Jeng et al., 2004)

Where the g_i is the i th intercept grain length in the traverse and t is the total traverse length. It gives an relative percentage of the length of the sandstone occupied by the grains. In other words it basically represents the closeness or spreadness of the particles. Higher packing density particles means the particles are closed and tightly packed (Ulusay et al. 1994). It can also be said that higher packing density sample have less matrix content.

The contacts observed in the sandstones are of different types i.e grain to grain contact (G-G).matrix to matrix contact (M-M), matrix to grain contact (M-G), porous particle to porous particle contact (P-P).

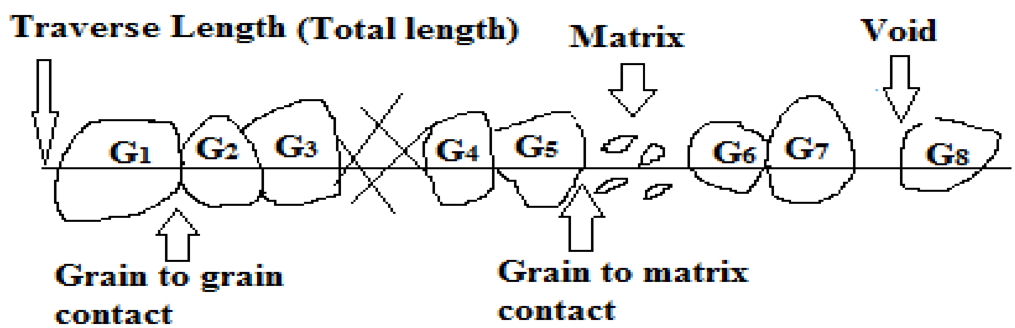


Figure 3.10: Grains in a traverse

Packing proximity is defined as the ratio of the number of grain contacts to total number of contacts along the traverse (Kahn, 1956). Packing proximity basically represents whether the particles are properly interlocked or not. Higher packing proximity with less cement or matrix represents the grains are tightly packed (Ulusay et al. 1994).if the particles are properly interlocked with smaller grain sizes then the packing proximity increases. It is generally found out by the following formula.

$$\text{Packing proximity, Pp} = \frac{\text{Number of grain to grain contact in the traverse}}{\text{Total number of contact in the traverse}} \times 100\ (\%)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ENGINEERING PROPERTIES

4.1.1 Unconfined compressive, point load and Brazilian tensile strength

Various engineering properties values are given in Table 4.1. Unconfined compressive strength of the rock is worldwide accepted as one of its strength parameters. In this test the load is applied in one direction i.e without any confinement of the rock specimen. In this study the strength of the sandstones are found to be varied from 13.82 MPa to 47.4. The strength of the coarse grained sandstone have been found to be less as compared to the fine grained sandstone. The higher value is associated with fine grained sandstones of WCL and ferruginous sandstones of JPL mines. However in case of MCL and WCL coarse grained sandstone the strength of the sandstones are found to be less. Almost similar variation of strength of sandstone have been found in Nepal Subhimalays and Qwa QWa, South Africa, where the strength of the sandstones are varied from 1.29 to 48.4 and 8.3 to 56.7 respectively (Tarmakar, 2007; Mumbiayi., 2013). But relatively higher values of strength haven found in Turkey, England and Iran (Zorlu et al., 2008; Bell, 1978).

This is an indirect method of measurement of strength of the rock. Both core and lumpy samples can be tested in this test. In this study point load strength is determined by using the core samples. Here load were applied from two different ways i.e the along the axis of the specimen or along diametrical direction. The rock core is generally tested along diametrical direction. In our tests the Point load strength has been found to be varied from 0.36 MPa to 5.38 MPa (Table 4.1) The lesser values of point load strength has been found in coarse grained sandstones of WCL and MCL mines. The shaly sandstones of JPL are having little bit higher values. However the ferruginous sandstones of JPL have the highest value of the Point load strength. Similar PLS values were reported from Greece and Zongula Dak sandstones from Turkey (Zorlu et al., 2008; Sabatakakis et al., 2008). But the sandstones from Jurasic ,Iran found to be varied from 3.66 MPa to 5.02 MPa (Heidari et al., 2013).

The rock is weak in tension. This is an indirect method of measurement of tensile strength of the rock. In this case compressive load is applied diametrically to the sample which is placed in between the platens. The compressive strength in diametrical direction produces a tensile stress along a plane other than the axis of the sandstone. The fracture is created along the tip of the contacts of the specimen. The sandstones which are tested for tensile strength have found to be varied from 0.22 to 6.98 MPa. The coarse grained sandstones are of lesser tensile strength. Relatively higher strength has been found for shaly sandstones and highest values of tensile strength have been found for ferruginous sandstones which is up to 7.2 MPa.

Table 4.1: Strength parameters of the sandstone

	Types	Mines	U.C.S (in MPa)	P.L.S(in MPa)	B.T.S (in MPa)
1	Coarse	WCL	13.82	0.47	1.105
2	Coarse	WCL	16.58	0.47	1.38
3	Coarse	WCL	18.2	0.48	1.5
4	Coarse	WCL	13.82	0.49	1.11
5	Fine	WCL	38.68	1.18	1.38
6	Fine	WCL	47.4	1.3	1.46
7	Fine	WCL	44.209	1.23	1.38
8	Shaly Sandstone	JPL	34.49	0.925	5.67
9	Shaly Sandstone	JPL	37.58	1.02	5.79

10	Shaly Sandstone	JPL	21.83	0.93	5.67
11	Fine	JPL	40.17	5.19	6.98
12	Fine	JPL	41.91	4.8	6.55
13	Fine	JPL	45.8	5.76	7.09
14	Medium	JPL	20.52	0.55	1.96
15	Medium	JPL	17.57	0.93	2.18
16	Medium	JPL	13.82	0.47	1.105
17	Coarse	MCL	15.86	0.36	0.22
18	Coarse	MCL	15.86	0.36	0.4
19	Coarse	MCL	24.83	0.98	5.72

From the Figure 4.1 and Figure 4.2 it is observed that UCS, PLS, BTS are significantly positively correlated with each other. The point load strength index has been widely used to estimate the uniaxial compressive strength of rocks in the field and laboratory (Deere and Miller, 1966; Broch and Franklin, 1972; Bieniawski, 1975; Gunsallus and Kulhawy, 1984; Ghosh and Srivastava,1991). In this study it has found that as the point load strength increases with increase in U.C.S vaue. Many studies present a direct relationship between UCS and BTS values (Tugˇrul and Zarif, 1999; Shakoor and Bonelli, 1991; Tugˇrul and Gu¨rpinar, 1997). Therefore, it is logical to compare the effects of micro scale parameters on UCS values with their effects on BTS values. Also Tugˇrul and Zarif (1999) mentioned that the tensile strength of rock is controlled by the same factors, mostly mineral composition and texture, as compressive strength. In this study it has also been found that the B.T.S has also found to be increased with the increase in U.C.S. In coarse grained sandstones a lower value of B.T.S is observed for lower values of U.C.S. However the U.C.S of sandstones of fine grained sandstones of WCL and ferruginous sandstones of JPL are almost in same ranges. But a higher values of tensile strength is observed for ferruginous sandstones .This may be due to the increase in iron content.

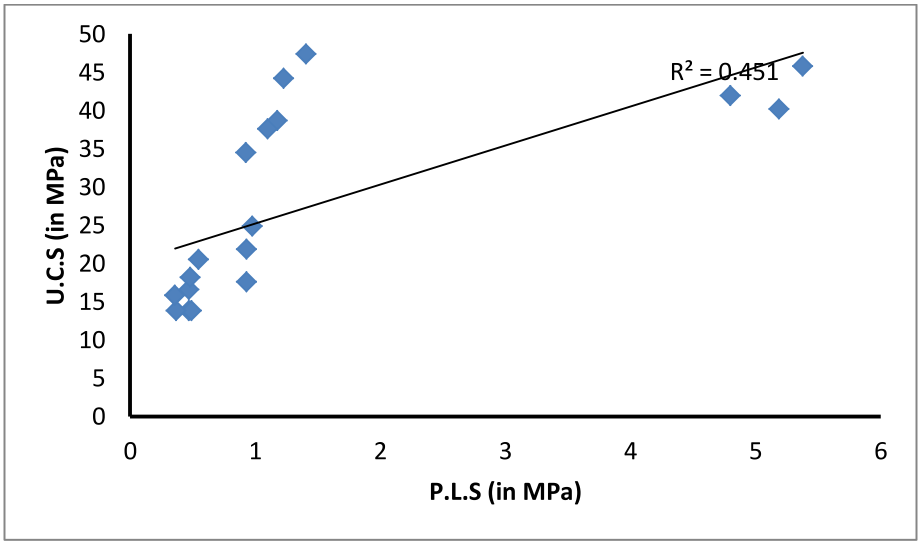


Figure 4.1: Variation of U.C.S with P.L.S

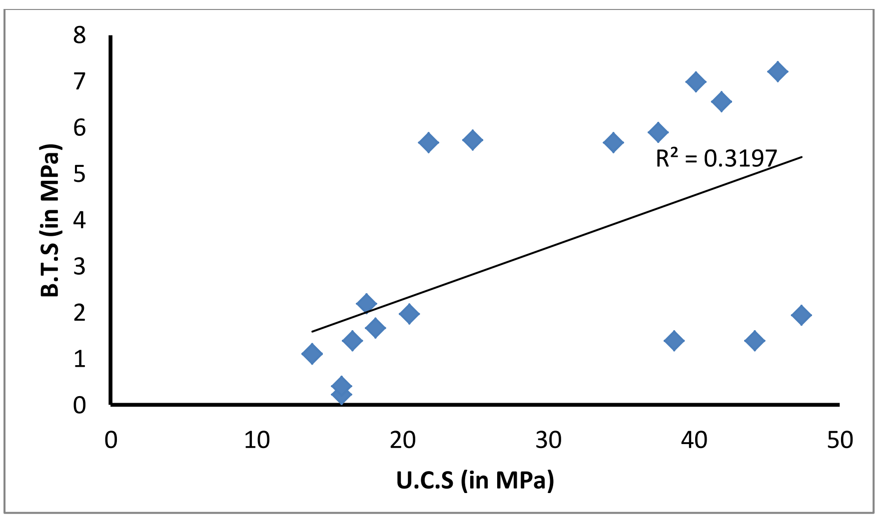


Figure 4.2: Variation of B.T.S with U.C.S

4.1.2 Dry density, Saturated Density and Porosity

Basically density is defined as the ratio of mass to volume. The dry density is the ratio of mass to volume when it is totally dried. In this study the dry density have found to be varied from 1.85 g/cc to 2.45 g/cc. The dry density has been found to be less for coarse grained sandstones of MCL and WCL which is from 1.85 to 2.16. However higher values of density have been found for shaly sandstones and ferruginous sandstones of JPL.

Saturated density is the ratio of the mass and volume of the specimen when the specimen is totally saturated. Generally it is measured by placing the whole specimen inside water and measuring the mass after placed for 48 hours. So that its all the pore spaces are occupied by water. If the rocks are having same dry mass and same volume and among them one has more amount of pore spaces then saturated density has been found to be increased. In In this study the saturated density has been found to be varied from 2.02 g/cc to 2.61 g/cc. The increase in density after immersion in water have been found to be more for coarse grained sandstone of WCL and MCL as compared to fine grained sandstones. This may be the reason behind the increase in porosity of the coarse grained sandstone.

Porosity is defined as the ratio of porous volume of (V_p) the rock to that of the bulk volume or total volume (V_T) of the rock. While determining porosity first the sample is oven dried so that proper estimation of the water which occupies the pore spaces can be done.

So porosity (η) = (Porous Volume)/(Total volume)

$$= (V_p)/ V_T$$

Porosity of the tested samples have been found to be varied from 10.1% to 18.34% .A similar situation is observed at Nepal Subhimalays where the maximum value of porosity is 19.1 % (Tarmar et al., 2007). But the porosity of the sandstones of sandstones from Turkey and South Africa are of values from 0.6% to 7.9% and 5.6% to 10.1% respectively (Zorlu et al, 2008; Bell and Lindsay, 1999)

Table 4.2: Porosity of the sandstone

	Type	Mines	Dry Density(g/cc)	Saturated Density(g/cc)	Porosity (%)
1	Coarse	WCL	1.97	2.152	17.45
2	Coarse	WCL	1.85	2.03	17.69
3	Coarse	WCL	2.01	2.18	17.35
4	Coarse	WCL	1.91	2.1	18.1
5	Fine	WCL	2.28	2.45	15.79
6	Fine	WCL	2.47	2.61	14.6
7	Fine	WCL	2.28	2.43	15.02
8	Shaly Sandstone	JPL	2.23	2.35	11.72
9	Shaly Sandstone	JPL	2.32	2.43	11.45
10	Shaly Sandstone	JPL	2.1	2.38	11.64
11	Fine	JPL	2.342	2.45	10.8
12	Fine	JPL	2.35	2.46	11.8
13	Fine	JPL	2.4	2.5	10.1
14	Medium	JPL	2.164	2.317	15.25
15	Medium	JPL	2.17	2.35	15.1
16	Medium	JPL	1.86	2.03	17.2
17	Coarse	MCL	1.89	2.02	17.24
18	Coarse	MCL	1.85	2.07	18.34
19	Coarse	MCL	2.16	2.28	12.21

Effect of porosity on Strength values

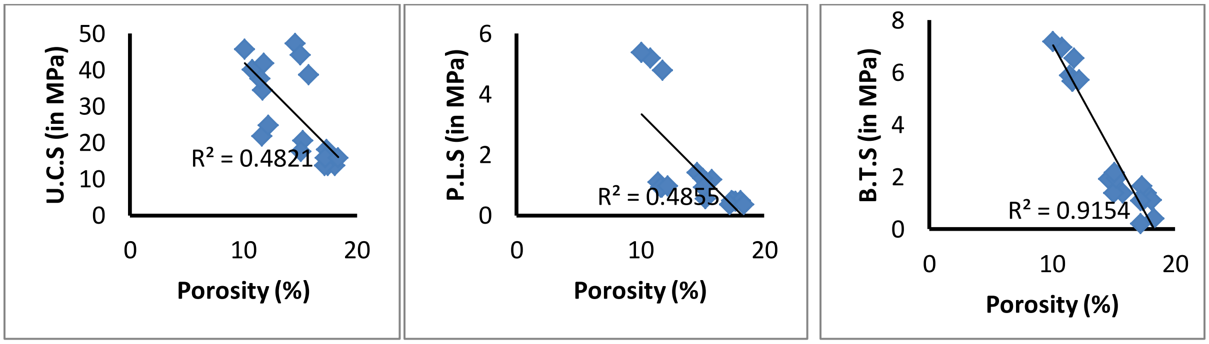


Figure 4.3: Variation of Strength of sandstone with porosity

Unconfined compressive strength was found to be increased when porosity decreases (Rashed et al., 2014).The unconfined compressive strength of the sandstones of Turkey and South Africa are 55MPa to 96 MPa , 17.5MPa to 214 MPa (Zorlu, et al., 2008; Bell and Lindsay, 1999). As discussed earlier their porosity values vary from 2.4% to 4.9%, 0.6% to 7.9% and 5.6% to 10.1% respectively. If we compare them then these sandstones are of higher strength as compared to the sandstones which tested here. The reason behind the increase in strength is due to the decrease in porosity. It can also be seen in Figure 4.3. The P.L.S and B.T.S have also been found to be increased with decrease in porosity which is shown by its strongest relationship.

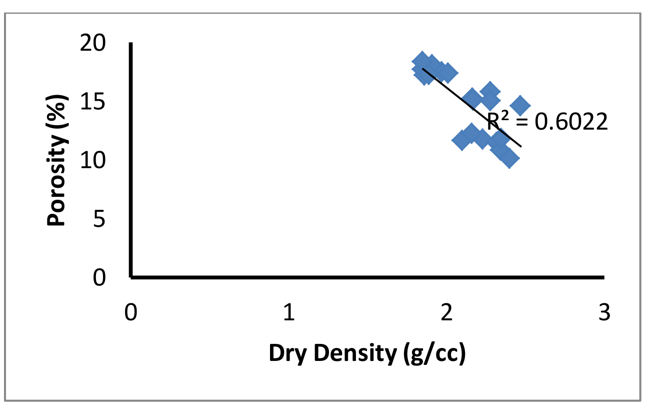


Figure 4.4: Variation of Porosity with dry density

The porosity of the rock decreases as the dry unit weight increases (Rashed et al., 2014). So the dry unit weight is negatively correlated with the porosity. It has also been found that the dry unit weight is inversely correlated with porosity (Figure 4.4).

4.2 CHEMICAL COMPOSITION

Variations of chemical composition of the sandstones are given in Table 4.3. The is observed that concentration of Al_2O_3, SiO_2, CaO, Ti, K_2O, Na_2O, MgO, Mn, Fe_2O_3, SO_3 found to be varied from 16.48 to 37.8 wt%, 35.73 to 62.28 wt%, 0.02 to 0.23 wt%, 0.052 to 0.73 wt%, 0.33 to 0.995 wt%, 1.67 to 3.98wt%, 0.104 to 0.2 wt%, 0.47 to 2.32 wt%, 0.014 to 0.57 wt%, 1.8 to 40.16 wt%, 0.16 to 0.452 wt% respectively. The analysis have suggested that Al_2O_3 and SiO_2 are the dominant oxides in most of the sandstone, which is possibly to due alternation of primary minerals to clay. The relationship among various chemical parameters and engineering properties of rock are given in Table 4.4.

Table 4.3 Variation of chemical composition of sandstone

	Al_2O_3	SiO2	P_2O_5	CaO	Ti	K_2O	Na_2O	MgO	Mn	Fe_2O_3	SO_3
Maximum	37.79	62.28	0.23	0.73	0.995	3.98	0.2	2.32	0.57	40.16	0.45
Minimum	16.48	35.73	0.02	0.052	0.33	1.67	0.104	0.47	0.014	1.8	0.16
Average	30.40	53.75	0.13	0.3	0.64	2.59	0.14	1.17	0.12	10.56	0.28
Standard deviation	6.002636	8.36	0.078	0.256	0.193	0.79	0.028	0.62	0.15	13.59	0.11

Table 4 .4 : Correlation matrix between chemical parameters and engineering properties of the rock

	Al2O3	SiO2	P2O5	CaO	Ti	K2O	Na2O	MgO	Mn	Fe2O3	SO3	U.C.S	P.L.S	B.T.S	Porosity	Dry Density	Saturated Density	Pcd	PP
Al2O3	1																		
SiO2	0.87	1																	
P2O5	-0.59	-0.6	1																
CaO	-0.54	-0.77	0.49	1															
Ti	0.8	0.68	-0.36	-0.35	1														
K2O	0.51	0.51	-0.9	-0.62	0.23	1													
Na2O	0.39	0.37	-0.41	-0.69	0.18	0.7	1												
MgO	-0.67	-0.89	0.39	0.79	-0.47	-0.38	-0.35	1											
Mn	-0.45	-0.55	0.49	0.71	-0.33	-0.55	-0.56	0.6	1										
Fe2O3	-0.96	-0.97	0.64	0.69	-0.76	-0.56	-0.4	0.81	0.54	1									
SO3	0.45	0.21	0.23	0.07	0.53	-0.33	-0.18	-0.18	0.16	-0.31	1								
U.C.S	-0.45	-0.67	0.56	0.94	-0.31	-0.69	-0.74	0.66	0.74	0.6	0.3	1							
P.L.S	-0.88	-0.94	0.49	0.81	-0.68	-0.47	-0.48	0.87	0.57	0.94	-0.37	0.67	1						
B.T.S	-0.86	-0.8	0.84	0.55	-0.71	-0.78	-0.48	0.57	0.54	0.87	-0.07	0.58	0.72	1					
Porosity	0.76	0.75	-0.89	-0.66	0.54	0.9	0.64	-0.57	-0.61	-0.8	-0.1	-0.71	-0.69	-0.96	1				
Dry Density	-0.48	-0.6	0.6	0.88	-0.28	-0.79	-0.86	0.56	0.74	0.57	0.25	0.92	0.64	0.64	-0.78	1			
Saturated Density	-0.4	-0.54	0.57	0.86	-0.23	-0.78	-0.83	0.53	0.73	0.51	0.27	0.9	0.58	0.6	-0.75	0.98	1		
Pcd	0.77	0.63	-0.78	-0.42	0.46	0.74	0.49	-0.44	-0.37	-0.73	0.16	-0.41	-0.62	-0.79	0.8	-0.48	-0.46	1	
PP	-0.71	-0.78	0.55	0.89	-0.47	-0.64	-0.68	0.72	0.74	0.78	-0.12	0.8	0.87	0.67	-0.73	0.88	0.85	-0.57	1

The SiO_2 concentration is attributed to the presence of silicate minerals (quartz, feldspar and muscovite), clay minerals, and siliceous cement. P.L.S and B.T.S varies inversely with percentage of SiO_2 as shown in Figure 4.5. Higher values of CaO indicate the presence of calcareous minerals in the sandstone as binding material and it has strong cementation properties. As the presence of calcareous cement increases the strength has found to be increased. The presence of Al is related to the abundance of feldspar, mica and clay. They basically form the major part of the clay mineral. Uniaxial compressive strength has found to be decreased with increase in clay content. The rocks which contain clay as binding material are weakest (Vutukuri et al., 1974).In this study we have found that there exist inverse correlationship between U.C.S, P.L.S and B.T.S with the K_2O and Na_2O (Figure 4.8) . Higher K_2O and Na_2O, is due to presence of feldspars and its altered product. The abundance of easily cleavable minerals (such as feldspars) causes a reduction in strength. Clay minerals are produced due to the chemical weathering and chemical decomposition of feldspars. In other words it can also be said that increase in these compounds decreases the cementing materials ultimately reducing the strength of the rock. The strengths (U.C.S, P.L.S, B.T.S) of the sandstone increases with the amount of Fe_2O_3 (%) in the sandstone (Figure 4.9) . It has been found that sandstones of VII O/B of JPL have the highest concentration of Fe_2O_3. Rocks containing ferruginous material cement are the strongest cement (Vutukuri et al., 1974). It increases the strength of the rock by binding the material strongly. It has also found that increase in siderite increase in density of the sandstone (Hatherly et al., 2007). It has also been found that increase in density ultimately increases the strength of the rock. Variation of strength with different chemical composition is given below.

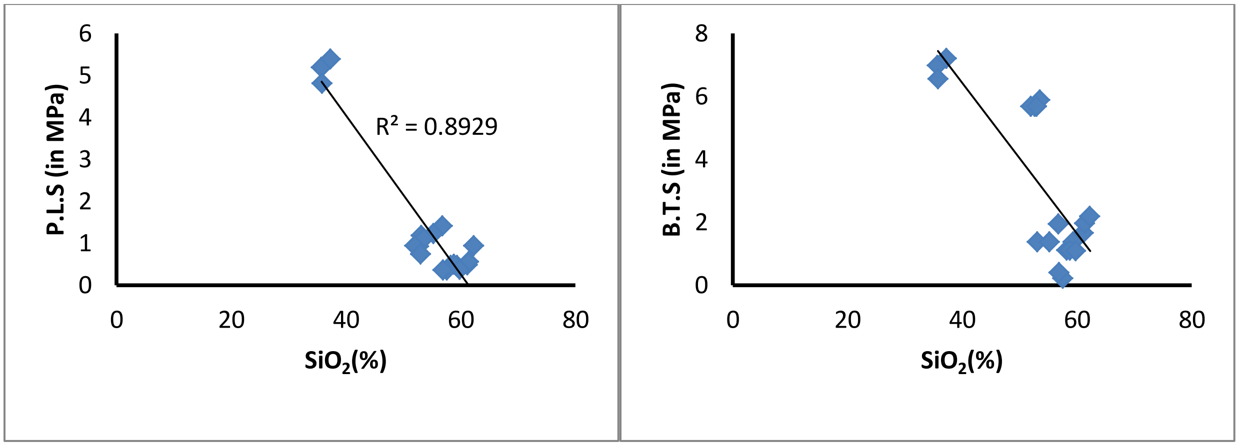


Figure 4.5 Variation of Strength with SiO_2 (%)

.

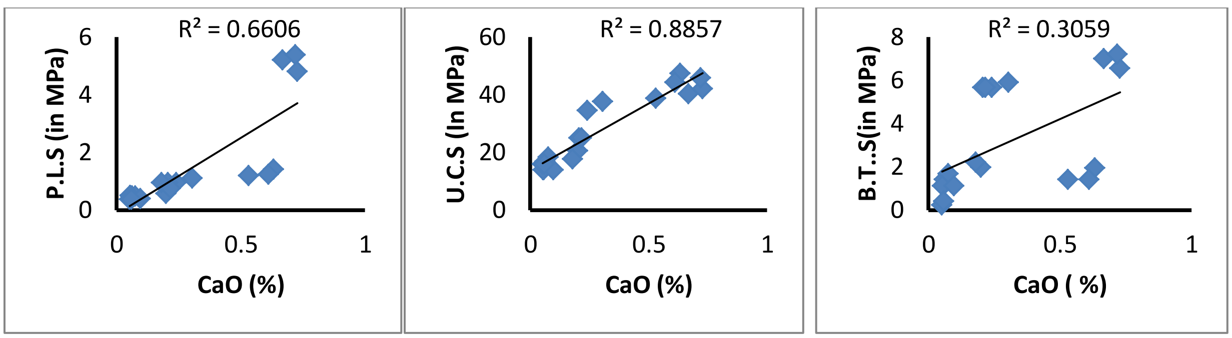


Figure 4.6: Variation of strength with CaO (%)

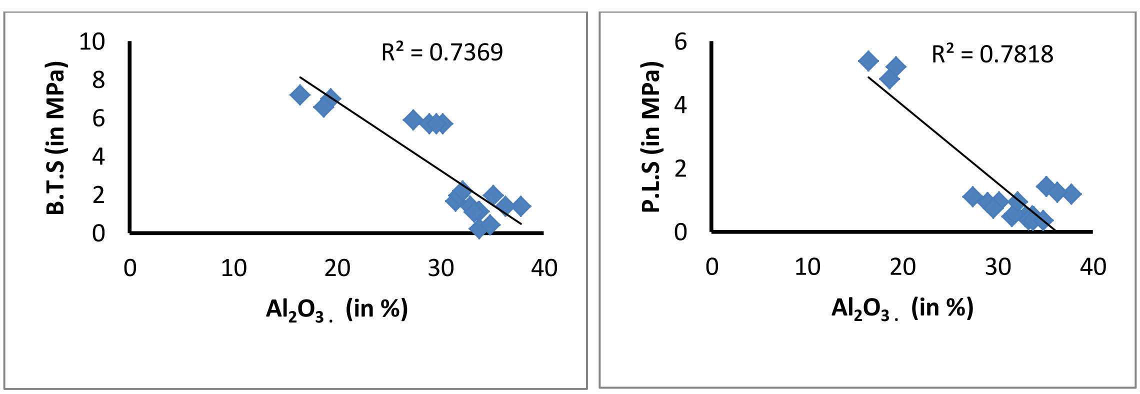


Figure 4.7: Variation of strength with Al_2O_3 (%)

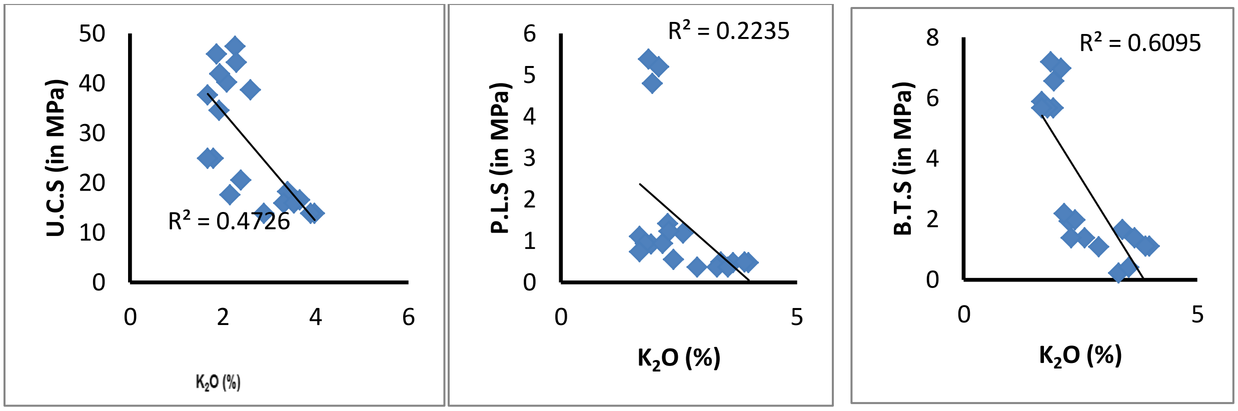


Figure 4.8 Variation of Strength with K_2O (%)

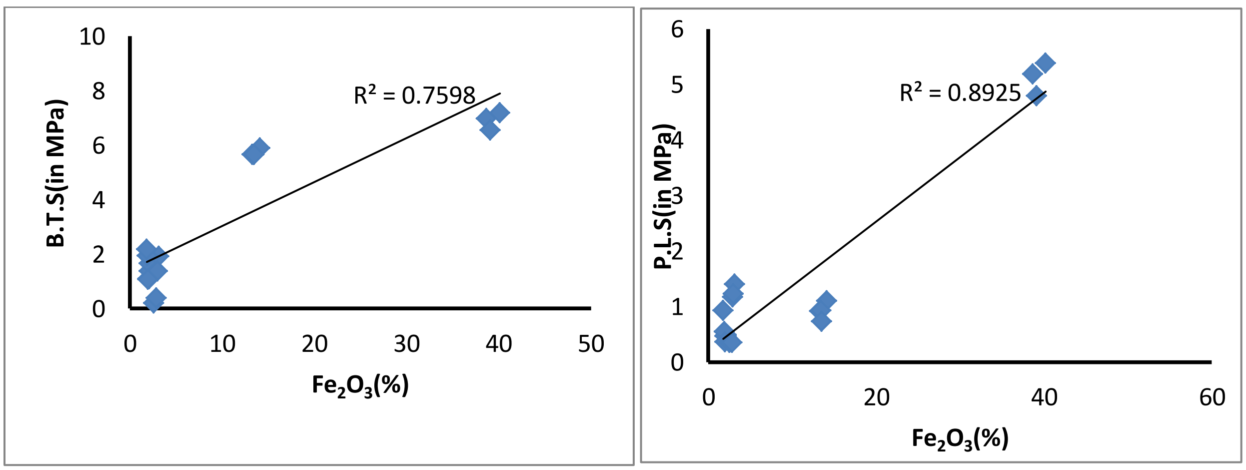


Figure 4.9: Variation of Strength with Fe_2O_3 (%)

4.3 MINERALOGY

X –ray diffractometry was applied to determine the mineralogy of the sandstone. Grain sizes of less than 200 micron size were allowed to be analyzed by XRD machine. The collected samples were prepared by placing them into plates which are air dried and coated with ethylene glycol. It is an import property which controls the strength of the rock. Quartz and feldspar minerals are the important minerals which affect the mechanical properties and the abundance of easily cleavable minerals such as feldspars causes the reduction in strength. The strength of the sandstone decreases with the size of the quartz, plagioclase and K-feldspar (Tugrul, 1999).The strength of the rock increases with increase in quartz to feldspar ratio (Keikha and Keykha, 2013).

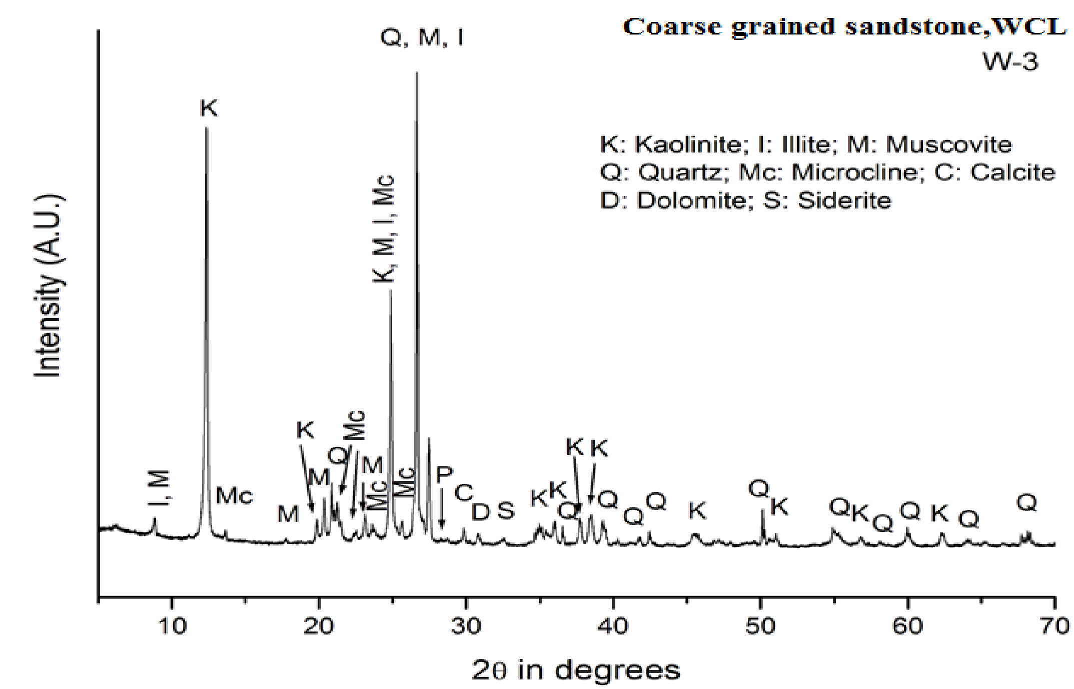


Figure 4.10: X –Ray diffraction pattern of sandstone

In most of the sandstones kaolinite and quartz are the dominant mineral as the higher peaks are of them. Clay minerals muscovite and microclines are moderately present. Siderite, calcite and dolomite are found to be in traces. The abundance of clay minerals increases the ratio of quartz to feldspar ratio, which ultimately decreases the strength of the rock.

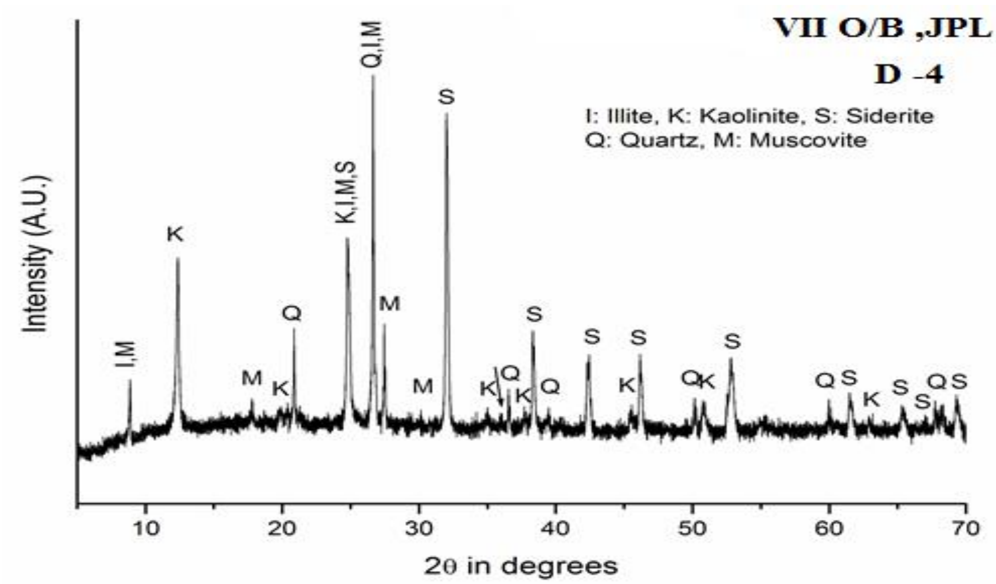


Figure 4.11: X –Ray diffraction pattern of ferruginous sandstone

In case of samples which are collected from VII O/B of JPL are found to be dominant in siderite, in addition of Kaolinite and quartz content.

4.4 TEXTURAL STUDY

The variation of geotechnical properties is mainly due to the variation of petrographic properties. Thin section analysis is basically carried out on the samples to study the arrangement of grains and its impact on strength of sandstone. Yates (1992) had found that strength was controlled by compaction and the extent of cementation. The textural interlocking of the quartz and cement grains is an important parameter than amount of quartz content in the context of strength (Bell and Cushaw, 1998). Therefore the sandstones are studied for the type of particles and cementation with the help of standard polarized microscope. Variations of petrographic properties values are given in Table 4.6. With respect of grain size both coarse and fine grained sandstones are found in WCL. However JPL and MCL sandstones are fine grained, coarse grained respectively. In sandstones the type of contacts which are observed are sutured, concavo-convex, long and point contacts Sutured and long contacts are observed in fine grained sandstones. But for coarse grained the contacts are mostly floating type. Petrographic study includes the study of packing density, type of contacts, total numbers of contacts and packing proximity of the rock. The variations of packing density and packing proximity are given below in Table 4.6. Packing density have been found to be varied from 28.2% to 86.75%.

Packing proximity have been found to be varied from 17.23% to 74.17%. It has been found that for coarse grained sandstones of MCL it was varied from 17.23% to 35.2%. However for medium grained sandstones of JPL it was from 28.1% to 45.3%. The fine grained sandstones of WCL is having value ranging from 36% to 62.45%. The shaly sandstones and ferruginous sandstones of JPL are having packing proximity values from 32% to 74.17%. The value is found to be increasing with decrease in grain size.

Table 4.5: Variation of Packing density and packing proximity

	Packing density	**Packing proximity**
Maximum	86.75	74.17
Minimum	28.2	17.23
Average	56.822	42.19
Standard Deviation	19.257	17.30

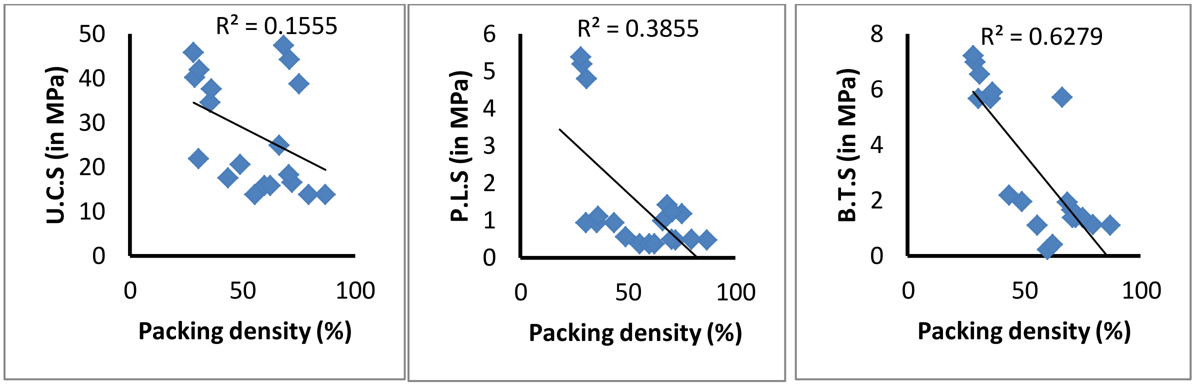


Figure 4.12: Variation of Strength with packing density

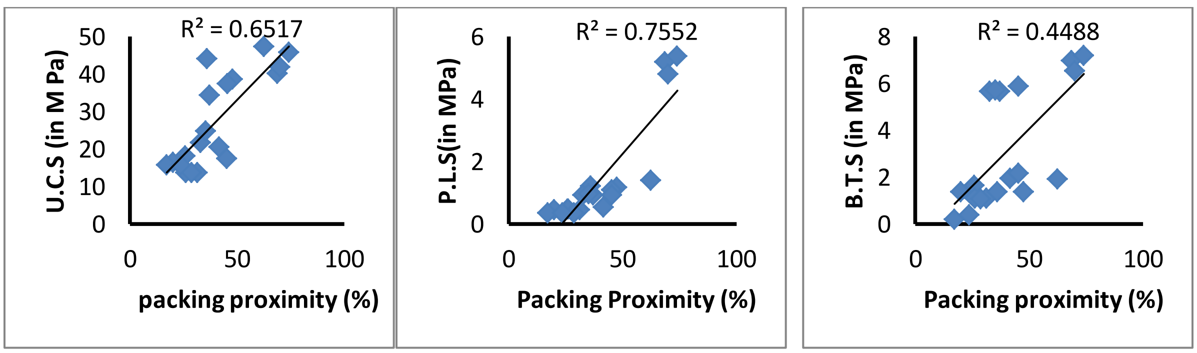


Figure 4.13: Variation of Strength with packing proximity

Figure 4.12 shows variation of strength with packing density. The Strength has found to be decreased with increase in packing density. But the effect of packing density on the strength of the sandstones is less as there is not much variation of packing density when the strength of the rock varies. It has been found that the strength of the rock increases with increase in packing proximity of the rock (Figure 4.13). Samples which are having lesser value of packing proximity are dominant by floating contacts between the grains. These type of contacts decreases the strength of the rock. If the packing proximity is high it means grain to grain contacts are more thus increasing frictional strength among the particles. The grains with sutured contacts have led to increase in strength of the rock.

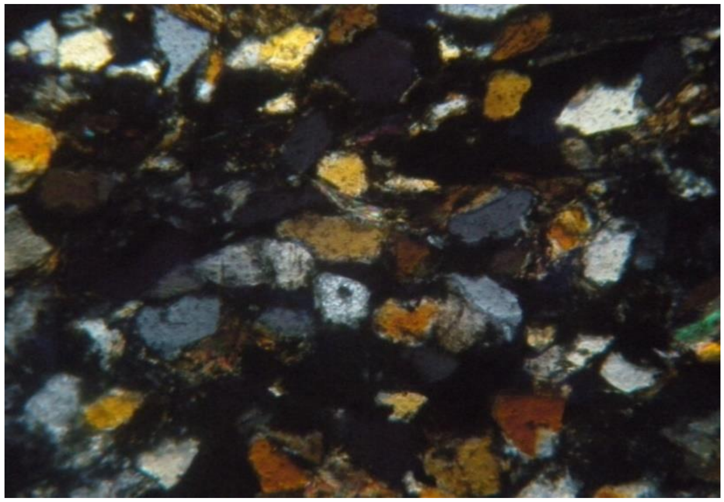


Figure 4.14: High Packing in fine grained sandstone

Fine grain sandstones have more number of contacts between the grain to grain, which have also been suggested by the increasing value of packing proximity (Figure 4.14). The types of contacts which are found are sutured contacts, concavo convex contacts and long contact. Coarse grained sandstones have floating contact and low packing proximity (Figure 4.15). It has been found that floating contacts have been observed in coarse grained sandstones of both WCL and MCL . In coarse grained sandstone alteration of feldspar, unstable rock fragments and rarely grain to grain contacts are observed in most of the samples. A strong statistical relationship was found between the total numbers of sutured contacts and the unconfined compressive strength and Brazilian tensile strength of sandstone (Richards and Bell; 1995).These contacts increase the strength of the rock as it can sustain higher amount of stress. The number of such contacts is higher for fine grained sandstones and the percentage of weak matrix is less as compared to other coarse grained sandstones. Besides these the particles are randomly oriented. So the U.C.S of such fine grained sandstones are of higher values of the ranges from 38.68 to 44.209 MPa.

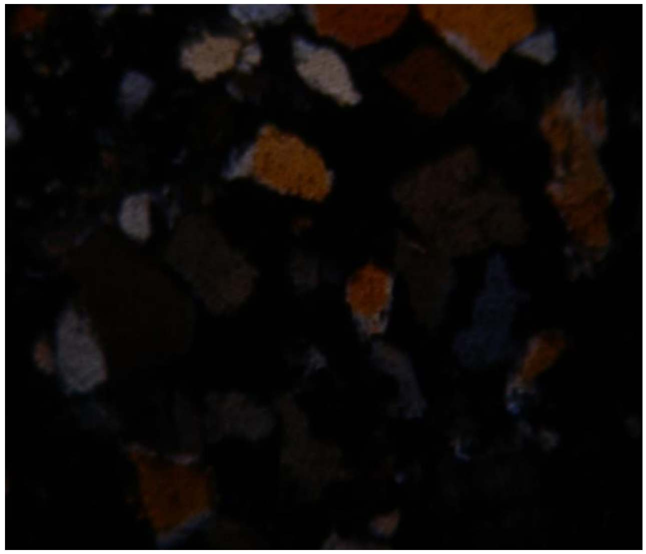


Figure 4.15: Coarse grained sandstone with floating contact

As shown in Figure 4.15 a relatively higher percentage of matrix is found in these coarse grained sandstones. Studies have shown that the strength has decreased with increase in matrix volume (Bell and Culshaw, 1998). The strength of the sandstone decreases when the majority of the portion of the sandstone is occupied by matrix because matrix constitutes of weak elements. As the matrix percentage increases, the no of contacts between the sandstones are less there by reducing the friction between the grains. So the strength of the sandstone decreases.So for coarse grained sandstone lower values of U.C.S obtained ranging from 13.82 MPa to 24.83 MPa. Similarly lower values of P.L.S and B.T.S were obtained which range from 0.36 to 0.74 MPa and 0.22 to 5.67 MPa respectively.

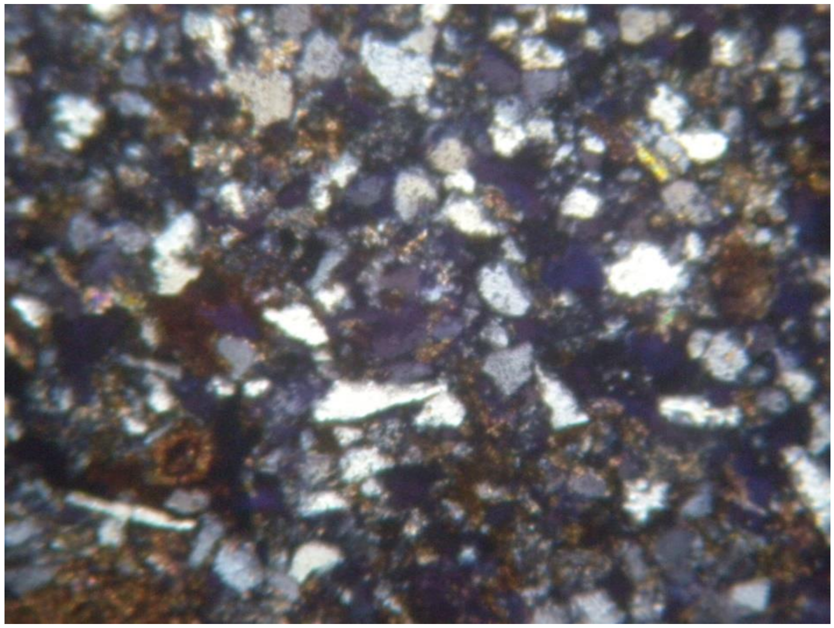


Figure 4.16: Fine grained sandstone with ferruginous cement, VII O/B JPL

In Figure 4.16 presence of ferruginous cement has also been identified. The presence of ferruginous cement increases the strength of the rock. If the amount of cement contact increases then the strength of sandstone has also found to be increased (Bell, 1978). Among the cements the rocks which contain ferruginous cement have higher strength as compared to the rocks which contains clay and calcite as binding material (Vutukuri et. al, 1974). In this type of sandstones as the particle size are less and amount of contacts between the ferruginous cement and the particles are more so a higher strength value is observed. Besides these for the ferruginous sandstones higher packing proximity is also observed. All these are the reason behind the higher values of U.C.S, P.L.S and B.T.S which are 40.17 to 45.8 MPa, 4.8 to 5.38 and 6.55 to 7.2 respectively.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

In this study sandstones samples were tested for various engineering properties such as U.C.S., P.L.S., B.T.S., density and porosity along with mineralogical, chemical and textural properties in order to evaluate their relationship. Strength increases with increase in Ca, Mg and Fe concentration as they form calcareous and ferruginous cementing material. The ferruginous sandstones of JPL have the higher strength as it is dominant in ferruginous cement. Strength is found to be increased with decrease in matrix percentage. It has also found to be decreased with increase in kaolinite content and alteration of feldspar. It is observed that find grain sandstone have better strength than coarse grained sandstone. Strength increases with increase in packing proximity,; however, inversely related to packing density. The fine grained sandstones of JPL show higher percentage of sutured and concavo-convex contacts which increases strength of the sandstone. Strength decreases with increase in porosity. The coarse grained sandstones of MCL is having the highest amount of porosity.

CHAPTER 6

REFERENCES

6.1 REFERENCES

- Bell, F.G., 1978. The physical and mechanical properties of the Fell Sandstone, Northumberland, England. Engineering Geology 12, 1-29.
- Bell, F.G., Culshaw, M.G., 1998. Petrographic and engineering properties of sandstones from the Sneinton Formation, Nottinghamshire, England. Quarterly Journal of Engineering Geology 31, 5-19
- Bell, F.G., Culshaw, M.G., 1998. Petrographic and engineering properties of sandstones from the Sneinton Formation, Nottinghamshire, England. Quarterly Journal of Engineering Geology 31, 5–19
- Bell, F.G., Lindsay, P., 1999. The petrographic and geomechanical properties of sandstones from the Newspaper Member of the Natal Group near Durban, South Africa.Engineering Geology 53, 57–81
- Cargill, J.S., Shakoor, A., 1990. Evaluation of empirical methods for measuring the uniaxial compressive strength of rock. International Journal of Rock Mechanics and Mining Sciences 27 (6), 495–503
- Chen, H., and Hu, Z. Y. 2003. Some factors affecting the uniaxial strength of weak sandstones. Bulletin of Engineering Geology and the Environment, 62(4), 323-332.
- Fahy, M.P., and Guccione, M.J., 1979. Estimating strength of sandstone using petrographic thin section data. Bulletin of the Association of Engineering Geology, 16, 467-485.
- Hawkins, A ., McConnell, B.J., 1990. Influence of geology on geomechanical properties of sandstones. 7th International Congress on Rock Mechanics, Aachen, pp. 257– 260

- Jeng, F.S., Huang, T.H., 1998a. Shear dilational behavior of weak sandstone. Proc. of Regional Symposium on Sedimentary Rock Engineering, Public Construction Commission of Taiwan, Taipei, Taiwan, pp. 262 – 267
- Prikryl, R., 2006. Assessment of rock geomechanical quality by quantitative rock fabric coefficients: limitations and possible source of misinterpretations. Engineering Geology, 87, 149– 162
- Sabatakakis, N., Koukis, G., Tsiambaos, G., & Papanakli, S. 2008. Index properties and strength variation controlled by microstructure for sedimentary rocks. Engineering Geology, 97(1), 80-90.
- Shakoor, A., Bonelli, R.E., 1991. Relationship between petrographic characteristics, engineering index properties, and mechanical properties of selected sandstone. Bulletin of the Association of Engineering Geologists 28, 55 – 71
- Shakoor, A., Bonelli, R.E., 1991. Relationship between petrophysical characteristics, engineering properties and mechanical properties of selected sandstones. Bulletin of the Association of Engineering Geologists 28, 55– 71
- Singh, V.K., Singh, D., Singh, T.N., 2001. Prediction of strength properties of some schistose rocks from petrographic properties using artificial neural Networks. International Journal of Rock Mechanics and Mining Sciences 38 (2), 269– 284.
- Tamrakar, N.K., Yokota, S., Shrestha, S.D., 2003. Petrography of the Siwalik sandstones, Amlekhganj–Suparitar area, central Nepal Himalaya. Journal of Nepal Geological Society 28,41– 56

- Tugrul, A., Zarif, I.H., 1998. The influence of mineralogical textural and chemical characteristics on the durability of selected sandstones in Istanbul, Turkey. Bulletin of Engineering Geology and the Environment 57, 185– 190
- Ulusay, R., Tureli, K., and Ider, M.H., 1994. Prediction of engineering properties of a selected litharenite sandstone from its petrographic characteristics using correlation and multi-variate statistical techniques. Engineering Geology, 37, 135-157
- Yates, P.G.J., 1992. The material strength of sandstones of the Sherwood Sandstone Group of North Staffordshire with reference to microfabric. Quarterly Journal of Engineering Geology 25, 107– 113
- Zorlu, K., Ulusay, R., Ocakoglu, F., Gokceoglu, C., Sonmez, H., 2004. Predicting intact rock properties of selected sandstones using petrographic thin-section data. International Journal of Rock Mechanics and Mining Sciences 41 (1), 93– 98